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(71) Applicants
E.M.I. Limited,
Blyth Road,
Hayes,
Middlesex.
(72) Inventors
Roger Voles
(74) Agents
R.G. Marsh

(54) Holographic imaging using electromagnetic waves

(57) An array of antennae comprises linear transmitter antennae 10 interleaved with receiver antennae 11. The array is focussed to produce a narrow vertical beam. An object to be imaged, e.g. a gun hidden under clothing of a person, moves horizontally past the array as the person moves. The beam is scanned vertically by selectively connecting the transmitter antennae in a preset order to a coherent source of microwaves comprising a stalo 6 and coho 7 and by connecting the receiver antenna in a preset order via a mixer 12 receiving the output of the stalo 6 to a phase sensitive detector 13 which also receives the output of the coho 13, and which detector feeds signals I and Q representing phase difference between the phase of the coho and the phase of waves reflected from the object to a signal processor. The signal processor includes a beam former which computes from the signals I and Q the components I', Q' (which would have been produced by a large number of beams of high resolution in the vertical direction) of the phase differences due to reflections from respective resolution cells in the vertical strip. The processor operates on the signals to ensure that there is a desired contrast in phase.

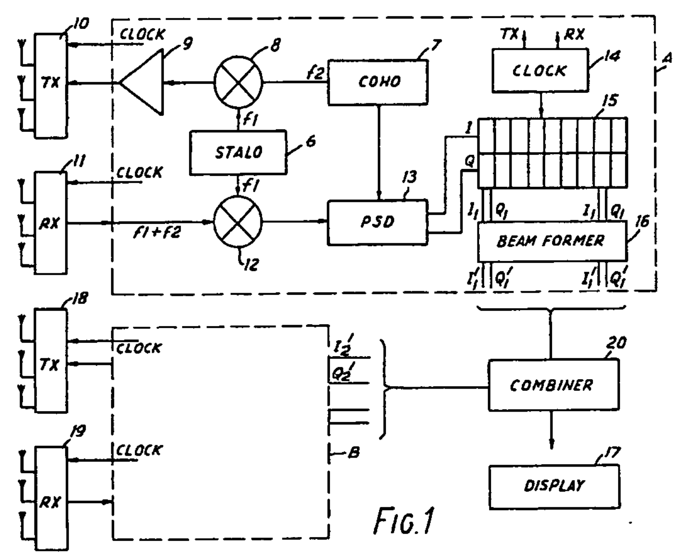

FIG.1

The drawing(s) originally filed was/were informal and the print here reproduced is taken from a later filed formal copy.

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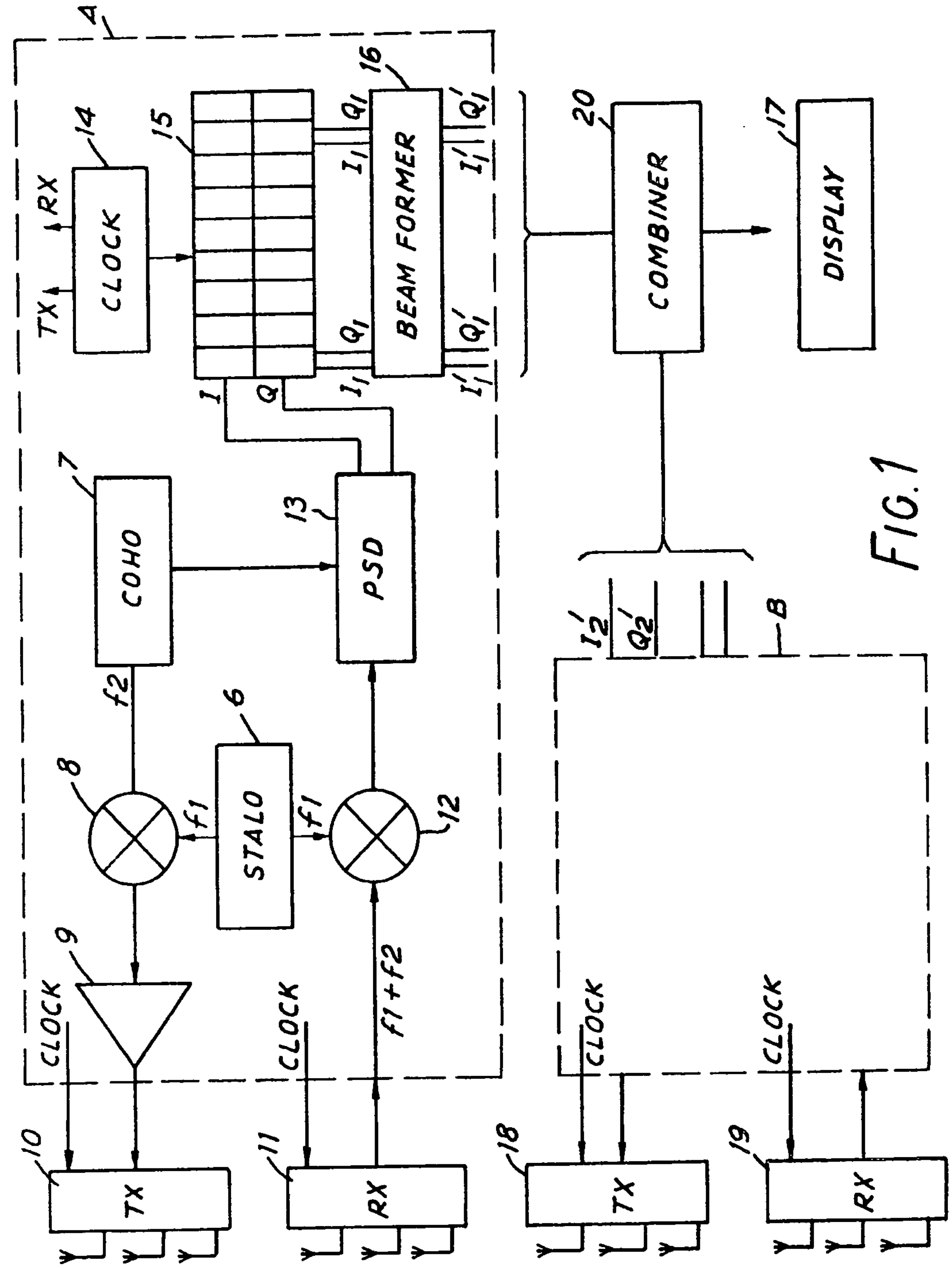

FIG.1

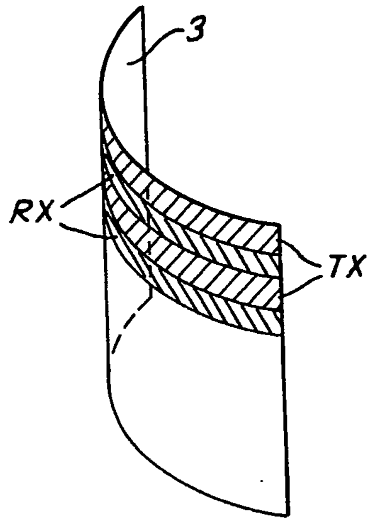

FIG. 2

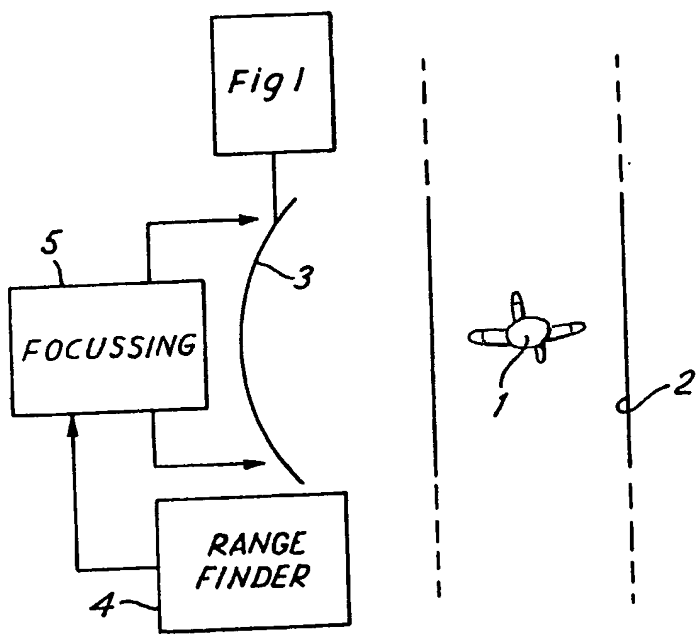

FIG. 3

SPECIFICATION

Holographic imaging using electromagnetic waves

The present invention relates to apparatus for producing an image of an object.

An article entitled "Millimeter Wave Holographic Imaging of Concealed Weapons" by N.H. Farhat and W.R. Guard in the "Proceedings of the I.E.E.E. September l971", pages 1383 and 1384 describes the production of an image of a toy gun by irradiating it with microwaves at 70 GHz and mechanically moving a receiver horn in a spiral to scan the phase distribution of the wave field scattered by the toy gun. The image of the gun is reconstructed from the phase distribution.

The use of mechanical movement makes the arrangement described in the article too slow to produce an image of the toy gun in real-time. Furthermore, no account was taken of the fact that in practice a real weapon would often by lying against the body of its owner which would also scatter the microwaves.

It is an object of the present invention to provide apparatus for producing signals representing an image of an object using electro-magnetic waves which apparatus has the capability of enabling the production of an image in real-time having a desired contrast.

According to the invention, there is provided apparatus for producing signals representing an image of an object, comprising

an array of antenna arrangements,

a source of coherent electromagnetic waves having a reference phase,

a signal processor, and

means for connecting the antenna arrangments to the source to irradiate an object with a wave field and to the signal processor so that the processor receives samples of the wave field reflected from the object, the samples being due to transmissions from and/or receptions by respective ones of the antenna arrangements successively selected by the connecting means,

the signal processor being arranged to be substantially insensitive to the amplitudes of the samples and to produce, from the samples and from the reference phase, signals representing values of phase difference between the reference phase and phases of waves reflected from different portions of the object, different ones of the values having at least a predetermined minimum difference in value therebetween, the signals representing an image of the object.

For a better undertstanding of the pesent invention, reference will now be made, by way of example, to the accompanying drawings, in which:-

Figure 1 is a block diagram of an imaging apparatus embodying the invention,

Figure 2 is a schematic diagram of an antenna array of the imaging apparatus, and

Figure 3 illustrates the manner of use of the apparatus.

Referring to Figure 3, it is assumed that a person 1 is carrying a weapon such as a hand-gun, concealed beneath clothing. The person is assumed to be walking at a maximum speed of 2*m*/s on a pavement which is 4*m* wide. It is also assumed that the weapon will be within a height bracket of 1.5*m*, and an imaging resolution of 1*cm* is adequate for recognition of the weapon.

The imaging apparatus comprises an antenna array 3, 2*m* to one side of the pavement. The apparatus irradiates the person with microwaves at about 96 GHz, a frequency chosen for its penetration of clothing. A lower frequency e.g. 70 GHz may be used. In order to achieve the assumed resolution 1*cm* at 96 GHz and the maximum range of 6*m*, the aperture of the array is 1.8*m*.

As shown in Figure 2, the array comprises a plurality of linear transmitter antennae TX, interleaved with a plurality of linear receiver antennae RX.

The array is arranged to produce a mircrowave beam which is directed in the manner described hereinafter into a strip which is narrow horizontally and broad vertically. As the depth of field is small at the minimum range, it is necessary to mechanically warp the array in a horizontal plane to focus it. For this purpose a range finder 4 is provided which controls a focussing arrangement 5 which mechanically warps the array. The range finder may be a laser range finder using non-visible laser light.

The person is scanned vertically and horizontally as he passes the array 3. The horizontal scanning is achieved by his own motion through the narrow vertical beam. The vertical scanning is achieved by one dimensional microwave holography as described hereinafter.

Referring to Figure 1, a stable local oscillator 6 produces a microwave of frequency $f_1 = 96$ GHz. A coherent oscillator 7 produces a phase reference signal of intermediate frequency f_2. A mixer 8 adds the frequencies, and an amplifier 9 applies the output of the mixer to a switching arrangement 10 associated with the transmitter antennae TX.

Signals received by the receiver antennae RX are fed via another switching arrangment 11 to a further mixer 12 where they are mixed with a signal derived from the oscillator 6 to produce an I.F.signal which is fed to a phase sensitive detector 13 which also receives the phase reference signal from the oscillator 7.

The switching arrangements 10 and 11 comprise switches such as *p-i-n* diodes which operate under the control of a clock 14 to connect the transmitter antennae to the amplifier 9 in a preset sequence and to connect the receiver antennae to the mixer 12 in a preset sequence, thereby to scan the strip vertically.

Each transmitter antenna, in turn, emits a beam, which irradiates part of the vertical strip. By energising all the transmitter antennae in sequence the whole of the vertical strip is illuminated. While each transmitter antenna irradiates part of the vertical strip, receiver antennae are sequentially connected to the further mixer 12 to each receive reflections from the whole of the illuminated area. By doing this for all the transmitter antennae in sequence, reflections are received from the successive parts of the whole vertical strip.

In this way the person 1 (and the gun) are irradiated with a wave field by the transmitter antennae, and each receiver antenna samples the field reflected from the person (and the gun). The phase sensitive dectector 13 produces signals I and Q representing the quadrature components of the difference in phase between each sample and the reference phase, the I and Q samples representing reflections received by each of the receiving elements in turn. The components I and Q of the samples are stored in a store 15 under the control of the clock 14 at locations corresponding to the times at which they were produced. The store 15 may comprise shift registers formed by charge-coupled -devices. The components I and Q are fed to a beam former 16. In order to resolve 1*cm* within a height band of 1.5*m* implies the generation of 150 beams if a real beam former were used. The beam former 16 is a programmed computer which computes, using the techniques of microwave holography, from the components I and Q, the components I', Q' (which would have been produced by 150 real beams) of the phase differences due to reflections from respective resolution cells in a vertical strip along the person, thereby achieving the vertical scanning by microwave holography.

The components I' and Q' could be used directly to cause a display device 17 to display lines of constant phase which would produce a representation of the gun. Reflections from the body of the person are distinguished from those from the gun by detecting only the phase components, (representing range), (the apparatus being substantially insensitive to the strength of the received samples). In this way rapid changes in range, as at the edges of a gun are detected as rapid changes in phase. However, at the operating wavelength of 3*mm,* the phase would go through a complete cycle for a range shift of 1.5*mm.* As a weapon such as a revolver is unlikely to be thinner than about 9*mm,* the lines of constant phase will be much closer than necessary and will tend to "fill in" the image and make the interpretation more difficult. One way to improve the picture would be to process the phase components I' and Q' before display by dividing the phase shift by a suitable factor e.g. 9*mm*/1.5*mm* = 6, so that the presence of a revolver would introduce only one contour. In order to effect this division, it is necessary to take account of both quadrature components in order to preserve information about the magnitude and sign of the phase shift. This division could be effected by suitably programming the beam former 16.

Another way to improve the picture by reducing the number of contours, is to rely upon the "beat" between two images produced at the frequency of 96 GHz for example, and at another frequency separated from that frequency by 96/6 GHz = 16 GHz. Figure 1 shows an example of an imaging apparatus operating in this way. In the figure, block A contains the elements described above associated with antenna arrangements 10 nd 11 for producing the signals, having quadrature components I'_1, Q'_1, representing phase differences between the reference phase and reflections from a vertical strip along the person. In block A, the stable local oscillator operates at 96 GHz.

Block B is identical to block A, except its stable local oscillator operates at 80 GHz and is associated with two antenna arrangements 18 and 19, which are in fact the antenna arrangements 10 and 11, even though they are shown, for clarity, separately from the arrangements 10 and 11. The antenna arrangements 10 and 11 are shared by blocks A and B by time multiplexing. The sharing could take place using frequency diplexing. Block B produces signals 12, Q'_2 equivalent to I'_1 and Q'_1 respectively. The signals I'_1, Q'_1 and I'_2, Q'_2 are combined in a combiner 20 to produce quadrature components 1" and Q" as follows:

$$1'' = I'_1 Q'_2 - Q'_2 Q'_2$$
$$Q'' = I'_1 Q'_2 + I'_2 Q'_1$$

The components I" and Q" are then used to operate the display 17 to display lines of constant phase difference.

Rather than using a single arrangement shared by both blocks A and B, two separate antenna arrangements (as shown) could be used.

The display 17 may be a chart recorder which records the phase difference represented by the signals I'_1, Q'_1 or I", Q" as lines, the intensity of which are modulated according to the phase differences, across the width of the chart. The chart could be longitudinally driven at a rate corresponding to an average walking speed. Alternatively, use could be made of the laser range finder 4 (Figure 3) to measure the actual walking speed of the person 1 and to control the speed of movement of the chart accordingly.

An analogous display could be produced by electronic storage and display on a TV monitor.

Various modifications, in additon to those already described, could be made. Instead of the heterodyne apparatus described using both a stable oscillator 6 at 96 GHz and a coherent oscillator 7 producing a phase reference of intermediate frequency, a homodyne apparatus could be used. The homodyne apparatus could include a single oscillator and the phase sensitive detector 13 could compare the phase of that oscillator with the phase of the received signals.

Instead of the antenna arrangement shown in Figure 2, an antenna arrangement comprising a single transmitter antenna arranged to illuminate the whole vertical strip and a stack of receiver antennae for scanning the vertical strip could be used. However, although such an antenna arrangement requires only switches associated with the receiver antenna it needs many more switches than the arrangement described above.

It will be appreciated that the roles of the transmitter and receiver antennae could be reversed.

CLAIMS

1. Apparatus for producing signals representing an image of an object, comprising

an array of antenna arrangements,

a source of coherent electromagnetic waves having a reference phase,

a signal processor, and

means for connecting the antenna arrangements to the source to irradiate an object with a wavefield and to the signal processor so that the processor receives samples of the wave field reflected from the object, the samples being due to transmissions from and/or receptions by respective ones of the antenna arrangements successively selected by the connecting means,

the signal processor being arranged to be substantially insensitive to the amplitudes of the samples and to produce, from the samples and from the reference phase, signals representing values of phase difference between the reference phase and phases of waves reflected from different portions of the object, different ones to the values having at least a predetermined minimum difference in value therebetween, the signals representing an image of the object.

2. Apparatus according to Claim 1, wherein the said source has a stable oscillator of a first frequency and a coherent oscillator having a reference phase and means for combining the outputs of the oscillators to produce the said coherent waves, and further comprising a further source having a stable oscillator of a second frequency differing from the first by a predetermined amount, and means for combining the output of the stable oscillator with an oscillator having the said reference phase to produce a further coherent wave, and wherein the conecting means is arrnged to connect the antenna arrangements to the sources to irradiate an object with wavefields from each source and to the signal processor so that the processor receives samples of the fields reflected from the object, the samples being due to transmission from and/or receptions by respective ones of the antenna arrangements successively selected by the connecting means, and wherein the signal processor is arranged to receive samples due to each source and be substantially insensitive to the amplitudes of the samples and to produce from the samples and from the reference phase signals representing values of phase difference between the reference phase and phases of waves from each source reflected from different portions of the object, and to combine the signals so derived from each source to produce further signals representing values of phase difference between the reference phase and phases of waves from different portions of the object, which further signals have the predetermined minimum differences in value therebetween.

3. Apparatus according to Claim 1 or 2, wherein the array comprises a plurality of linear transmitter antennae interleaved with a plurality of linear receiver antennae.

4. Apparatus according to Claim 3, further comprising means for mechanically warping the array to focus it.

5. Apparatus for producing signals representing an image of an object substantially as hereinbefore described with reference to the drawings.

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